DOCUMENT RESUME

ED 191 732 SE 032 767

AUTHOR	Braun, Ludwig
TITLE	Some Bases for Choosing a Computer System: Suggestions for Educators. Technical Report No. 2.
INSTITUTION	State Univ. of New York, Stony Brook. Coll. of Engineering.
SPONS AGENCY	National Inst. of Education (DHEW), Washington, D.C.
PUB DATE	1 Aug 78
NOTE	52p.: Photographs and drawings of computers will not reproduce well.
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	Computer Graphics; Computer Oriented Programs; *Computers; *Computer Science; *Computer Science Education; *Educational Technology; *Elementary Secondary Education; Instructional Materials; Mathematical Vocabulary; Mathematics Curriculum; *Mathematics Education; Mathematics Materials; Resource Materials; Science Education; Vocabulary
IDENTIFIERS	*Computer Selection

ABSTRACT

This report reviews four different computer systems that are available for educational use. Presented is a system overview, and the strengths and weaknesses of each of the following systems: PLATO, TERAK, Compucolor II, and PET. Each of these machines is included as a representative of a "class" of machines available to the educator. Their selection for review is not intended as an endorsement, but rather to permit specificity in discussions of properties. The report looks at the characteristics of each of these machines as they pertain to educational applications, to aid educators in evaluating computer systems, and in making a good choice from among the multitude of systems offered in the marketplace. This document concludes with a comparison among these four computers based upon a set of 25 educationally important parameters and a glossary of technical computer-related terms. (MP)

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some bases for choosing a computer system: suggestions for educators

SE 032 767

TECHNICAL REPORT NO.2
Ludwig Braun

August 1978
Stony Brook, New York

SOME BASES FOR CHOOSING A COMPUTER SYSTEM: SUGGESTIONS FOR EDUCATORS

prepared for

The National Institute of Education

by

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August 1, 1978

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Disclaimer

The attached report was prepared at the request of the National Institute of Education; however, any opinions stated herein are those of the author and do not necessarily reflect the policy or opinions of the National Institute of Education or of its staff.

Preface

The attached report has been prepared at the request of the National Institute of Education. It represents an initial attempt to identify system parameters of importance to educators and to assess four representative computers in terms of these parameters.

Each discipline has its jargon which is incomprehensible to "outsiders." This problem is solved here by inclusion of a glossary of technical terms in Appendix A.

I. WHAT IS THE PROBLEM?

During the past decade, much of educational computing was done via time-sharing terminals and cost in the order of $3,000-$5,000 per-terminal-per-year to lease a terminal and to pay for access to a computer. This was the cost whether the service was provided by a nonprofit consortium (like TIES in Minneapolis) or by a profit-making corporation.

Another major source of educational computing was the minicomputer, either the stand-alone machine or the mini-time-sharing system. In either case, such computing cost about $5,000 purchase price plus $500-$1,000 each year for machine maintenance.

In 1975, a revolution in educational computing began with the announcement of the Altair 8800 microcomputer. In the intervening three years, prices have dropped dramatically, and computer performance has increased equally dramatically. These changes have been breathtaking and have simultaneously increased the options available to the educator and increased his/her dilemma.

The essential problem faced by the educator is expressed by the question "Which, of the many computing options available to me, shall I choose?" The answer appears to be simple and straightforward. We need only determine the cost of the system under consideration and the benefits provided by it and compute the cost/benefit ratio. The system with the lowest cost/benefit ratio is the most desirable system.

Unfortunately, the answer is neither simple nor straightforward. Neither the cost nor the benefits of a given system are easy to determine. The cost includes the purchase or lease price, but also includes the cost of developing courseware for use by students and teachers, maintenance cost, operating costs, and amortization period (for equipment purchases). Some of these costs are relatively easy to determine, but the cost of developing courseware is difficult

to evaluate. The amortization period also is difficult to define, primarily because obsolescence is not clearly determined. Many people consider the Digital Equipment Corporation PDP-8 to be obsolete, and in some sense it is. When the PDP-8 is compared to many of the new microcomputers, it is obsolete; however, the PDP-8 still is capable of providing considerable computing power to students and teachers. Many PDP-8's still are performing effectively after considerably more than a decade. Over how many years should the cost of a computer be spread? Two years? Five? Ten? Twenty-five? Clearly, computers don't wear out, and, so, the end point of their useful lives is defined only vaguely.

This last point is an important one for educators to realize. This author has been asked repeatedly by educators, "Shouldn't I wait a year or two before buying a computer so that things will settle down? Then I won't be stuck with an obsolete computer." The fallacy of this reasoning has two dimensions:

1. Computers do not become obsolete for years after their purchase.
2. The computer business will not settle down in a year or two, and probably not in a decade. In the past three years, new, more exciting microcomputers were announced almost monthly. Industry projections indicate that this trend will continue until well into the future.

The benefits of a specific computer are even more difficult to evaluate than the costs. There have been no objective evaluations (to the author's knowledge) of such matters as:

1. What contributions can color make to an educational activity? Most of us have color TV sets and prefer movies in color; most of us take pictures of our children in color; yet, how valuable is color? Is it worth $100, $500, $1,000 in added purchase price? No one knows the answer to the last question.

2. What resolution should be available in the graphics package on the computer? All of the computers considered in this report have some form of graphics available, with resolutions ranging from 512 x 512 (or 262,144 points) for PLATO through 40 x 25* for the PET. Is the level of detail available on PLATO a luxury, or is the level of graphics on the PET inhibitory? Is there some level between these extremes which is an acceptable compromise?

3. How valuable educationally is animation as an element of learning packages on the computer? No one would argue that animation is not useful; however, how many dollars in purchase price is it worth?

4. The value of connectedness of users is difficult to measure. Users in a connected (or time-sharing) system all are connected to a central machine and may communicate with one another directly from terminal to terminal, or by leaving messages in user files. This can be a very effective interpersonal communication vehicle and can, in a properly designed system, permit groups of users to work interactively with a single program even though they are widely separated geographically. It also permits free exchange of programs and data files among users.

An advantage of connectedness which should not be ignored by educators is the implied centralization of responsibility which exists in such systems. The central authority is responsible for system maintenance and, frequently, also is responsible to the user community for courseware generation, training, and consultation.

Unfortunately, connectedness usually also means dependence on a single main frame. If the machine "crashes," all users are without service. Further,

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* This is an unrealistically low description of the PET. Each of its 1,000 screen locations may be filled with any one of 128 symbols, or its reverse. Each of these symbols is composed of a subset of the 64 dots available in each character position. In some sense then, the resolution of the PET is better described as 320 x 200, although not all 64,000 dots are under user control. PET graphics probably are equivalent to 10,000-20,000 points.

the system is vulnerable to "attack" by clever students interested in demonstrating their prowess. Disconnected (i.e., stand-alone) systems are not subject to such problems, but they also do not make the benefits of inter-person or person-central file communication available.

There is a compromise which might be termed "semi-connected." There are stand-alone systems which may call up a central computer at any time to enter information into a central file or to transfer information from a central file to a local file. Such systems have most of the advantages of the connected system, but almost none of the disadvantages of either the stand-alone system or of the connected system.

How much value do we assign to these advantages and how much penalty to the disadvantages?

Additional elements which go into the cost/benefit equation will be considered in Section VII of this report.

One final matter related to computers in education which should be discussed is the concept of threshold of cost. Academic administrators have many demands pressed upon them by athletic directors, teachers, parents, governmental agencies, etc. Each of these demands is evaluated and acceded to or rejected depending upon whether or not the cost exceeds some perceived (but often unstated) threshold level.

Such thresholds are most clearly operational in fringe areas such as art, music, and computers. The cost threshold for computers may be evaluated by determining how much administrators <u>are</u> allocating for computing support of their educational programs.

On Long Island (where this author has most direct experience), the threshold for high schools seems to be about $2,500. At this level, about half the high schools in Nassau County and western Suffolk have one or more computer terminals into a computer consortium (ENCODE and LIRICS, respectively). Most have only one terminal. If the per-terminal cost were to halve, they probably

would acquire two terminals; if it should double, most would drop out.

At the elementary school level, the threshold is considerably lower. In this author's local school district, building principals may connect to the district's time-sharing system for $700 (the cost of terminal rental and telephone charges), but only three out of thirteen principals have installed such terminals. The junior high school principals, on the other hand, have installed two or three terminals in their buildings at this same cost.

Cost thresholds are not absolute. They reflect the cost/benefit ratios which we discussed earlier. Where an administrator perceives a benefit, his/her cost threshold goes up. Elementary school people are beginning to discover learning enhancements* produced by calculators and computers when used by their students, and we may expect to see their cost thresholds going up, and use of computational support available in schools increasing.

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* Excellent references for such learning enhancements are:

Calculators/Computers
P. O. Box 310
Menlo Park, CA 94025

People's Computers
Box E
1263 El Camino Real
Menlo Park, CA 94025

These two publications focus on educational applications of calculators and computers, especially at the elementary level.

II. THE APPROACH

The questions raised in Section I are among the questions raised by educators when they consider acquisition of computers for their schools. The purpose of this report is to address these questions and to aid educators in evaluating computer systems and in making a good choice from among the multitude of systems offered in the marketplace.

In order to clarify the issues and the options, this author has decided to look at four computer systems ranging widely in cost and in sophistication. The machines chosen cover the spectrum of possibilities in both dimensions. These machines are:

A. PLATO. This is the most advanced educational computer system available. If cost were not a consideration, this undoubtedly would be in every classroom in the United States. PLATO terminals do not have color, but otherwise they have just about every capability that an educator could want.

B. TERAK. This is a stand-alone computer system which has much of the capability of PLATO at relatively low cost. In some sense, this may be characterized as the "poor man's PLATO."

C. COMPUCOLOR II. The only machine in our study with color capability, this machine is the most recent entry into this field and is considerably less expensive than PLATO or TERAK.

D. PET. The lowest price computer in the group, the PET, nonetheless, is an important computer.

Each of these machines is included as a representative of a class of machines available to the educator. It is not intended that their selection should be an endorsement of these machines over others in their classes. These machines have been selected to represent their classes and to permit specificity in discussions of properties.

In subsequent sections, we shall look at the characteristics of each of tnese machines as they pertain to educational applications.

The report concludes with a comparison among these four computers based upon a set of educationally important parameters.

III. PLATO

A. System Overview

PLATO IV, the present PLATO system, is the result of a development effort which has been directed since 1960 by Dr. Donald Bitzer of the University of Illinois at Urbana. Many millions of dollars have been expended on the development of this system in the intervening eighteen years. The history of this development effort is described by Elizabeth R. Lyman [1].

The result of these efforts by an unusually creative group of people is the most powerful educational tool mankind has ever developed.

The PLATO system has three major elements:

1. Hardware. The primary hardware components are a computer configuration consisting of Control Data Cyber 73-24 and 6500 computers, communication hardware designed to permit up to 1,000 users simultaneously to use the computer, and user terminals.

The most obvious hardware component to the user is the PLATO terminal. This terminal has a screen (called a plasma screen) consisting of two plates of clear glass which enclose an inert gas. Under computer control, any one of more than 262,000 individual spots (usually described as 512-horizontal-by-512-vertical resolution) on the screen may be lit. This high resolution permits the generation of quite detailed graphic images. Because of the high screen writing rate (up to 3,000 characters per second) and high-speed selective screen erase (at up to 6,000 characters per second), authors may significantly improve their learning materials by including animated figures in these materials.

The terminal also includes:

a) A touch detector which can detect the touching of the screen at any one of 256 (i.e., 16 x 16) points. This permits students to indicate choices by pointing a finger at the screen.

b) Rear projection of any one of 256 randomly selectable frames from a microfiche card stored internally. This permits authors to combine still frames with computer-generated screen images.

c) Additional input-output channels to permit terminal control of auxiliary equipment, including:

(1) An audio disc with a total of twenty minutes of prerecorded information which is randomly selectable under computer control.

(2) A Votrax speech generator which permits the author to cause the computer to "speak" to the student.

(3) A music generator which permits the student to use the computer to assist in composition and generation of music.

(4) Hard-copy devices to permit students to obtain listings or outputs of selected computer runs.

(5) Joystick input to permit students to enter information in a tactile mode.

d) The terminal design permits communication with the central computer at low speed (hence permitting transmission over voice-grade lines) despite the high terminal speed.

In September, 1977, the latest PLATO terminal, the PLATO V, was announced. This terminal has a resident computer consisting of an 8080 microprocessor, 4K bytes of read-only memory and 8K bytes of random-access memory for user work space. This terminal includes also an eight-inch floppy disc system for program storage.

The PLATO V may be used as a stand-alone PLATO system or as a terminal into the PLATO main frame. Programs may be entered into the PLATO computer through the PLATO V terminal, compiled and then down-loaded

back to the terminal for storage on the disc. There also is a subset of PLATO resident in the terminal to make it a stand-alone system. This terminal offers great promise of reducing the user cost of PLATO. The current terminal cost is $5,300 plus the cost of the floppy disc (about $1,000). The PLATO V terminal is described by Stifle [2].

There are only two criticisms one might justifiably level against the PLATO terminal. They are the lack of color (the plasma screen is orange when lit, and black otherwise), and the cost ($6,000 - $7,000 is still a great deal of money in view of the cost-threshold phenomenon) mentioned in Section I above.

2. Software. The software which drives the PLATO system is very complex and is outside the scope of this report. The software component which is most obvious to the user is the TUTOR language. This language was designed to make authoring of courseware easy for non-programmers. There are many screen oriented commands which permit the author to: locate text starting at any point on the screen; draw dots, lines, circles, or boxes of any size and at any screen location and of any line thickness; and specify special characters to produce displays with foreign (e.g., Hebrew, Russian, or Farsi) symbols or to provide building blocks to create balloons, cars, octopi, etc.

TUTOR permits the author to develop CAI lessons, complex simulations, or problem-solving sessions.

Examples of screen displays generated on PLATO are shown in Figs. III.1 - III.3. In Fig. III.3, the ship and submarine sail across the screen under control of the users.

Another aspect of the system software which is important to the educator is the capability of PLATO to gather comprehensive performance

data on individual students as they work on PLATO. This permits the teacher to keep track of all his/her students' progress and permits the author to evaluate and improve his/her courseware.

3. Courseware. The PLATO courseware is the most extensive collection which exists anywhere. Over 6,000 hours of instructional material have been developed in more than 100 subjects ranging from elementary school through college level. Currently available materials are listed in a report by Lyman [3].

An excellent example of the impact of PLATO courseware was seen by this author on a recent visit to the fourth-grade classroom of Mrs. Nancy MacDonald at Urbana, Illinois. Mrs. MacDonald has had four PLATO terminals for the exclusive use of her students for each of the past three years. In each of these years, it has been her experience that all of her pupils have learned more mathematics than was the case prior to PLATO and that their attitude toward mathematics was much more positive--even with children who came into her class antagonistic to the subject.

Each child is scheduled for a daily half-hour session* on a terminal all through the school year. The students in this class have averaged two years growth in mathematical skills during fourth grade compared to one year's growth in similar classes in the same district who did not have PLATO terminals available. Details of the testing and the results as well as examples of curricular applications are described by Dugdale and Kibbey [4].

---

* Both Mrs. MacDonald and Dr. Robert Davis, Headmaster of the University School at the University of Illinois at Urbana, feel that this time allocation is essential. This means that an 8:1 student-to-terminal ratio is ideal.

You may see up to four flies at a time. When you are ready for your next request, move the arrow to the fifth position.

What fly do you want here?
stock x male ok

What fly do you want here?
stock x female ok

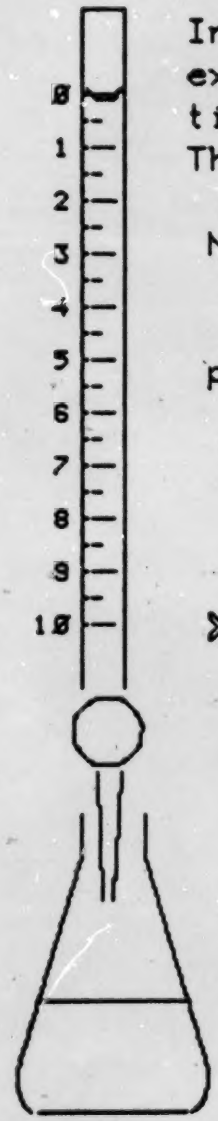
What fly do you want here?
stock y male ok

What fly do you want here?
»

12

Fig. III.1. One frame from a genetic simulation involving fruit flies.

Acid - Base Titrations
Standardization of an aqueous NaOH solution.



In this experiment you are to determine the exact concentration of a NaOH solution by titration of pure potassium acid phthalate. The base is about 0.1 M.

Now what do you want to do?
» titrate

press	To
T	Start Titration
S	Stop titration
+	Add base faster
-	Add base slower

»

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For help press HELP. To use a calculator press DATA

Fig. III.2. One frame from a titration simulation in a chemistry program.

Torpedo

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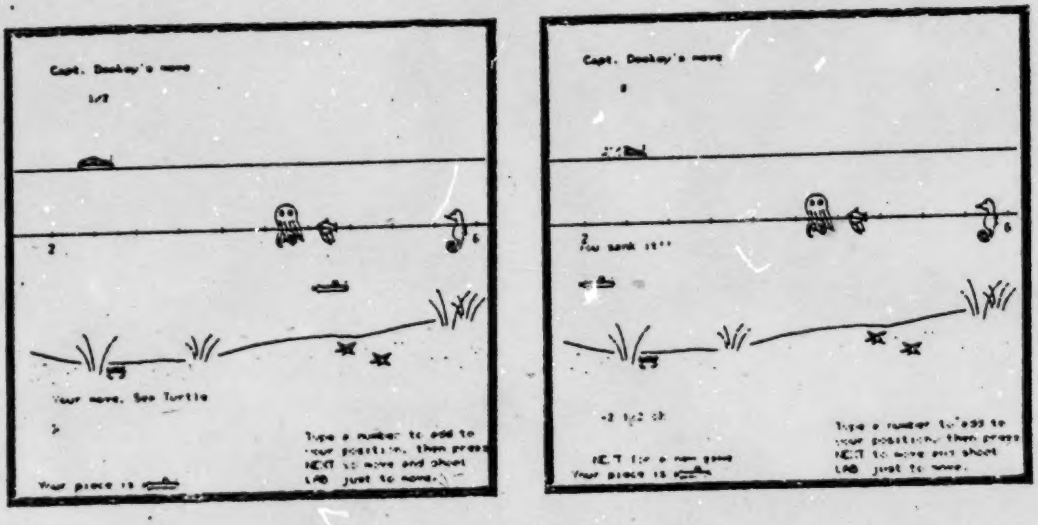

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Fig. III.3. Two frames from Decimal Torpedo, a part of a decimal-fraction syllabus in PLATO (4).

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B. The Strengths and Weaknesses of PLATO

In this section, we shall attempt to summarize the major strengths and weaknesses of PLATO from the viewpoint of the educator.

1. Strengths of PLATO

a) Excellent graphics capability. High resolution, animation, flexible character sets, high-speed displays.

b) Lots of courseware available at all academic levels and in many disciplines.

c) Excellent user terminal, easy to use, good keyboard, touch detector, rear projection possible.

d) Large base of experience, extensive evaluation data available.

e) Powerful authoring language oriented to the non-programmer. Permits development of wide range of educational experiences.

f) Teacher can get student performance data.

g) Very large memory space available to each user.

h) Interfaces to the real world are available: e.g., audio disc, voice generator, music generator, joystick.

i) Misspelled word detector. Accepts student inputs if spelling is approximately correct.

j) Permits author to include alternative phraseology of correct responses; e.g., "This is a right triangle."; and "Rt. triangle" are equally acceptable.

k) Connected system permits inter-person communication and interaction among remotely located groups executing a program. One example is seen in Fig. III.3, where one student controls the position of the submarine and another, who may be at a different site, controls the position of the surface vessel.

2. Weaknesses of PLATO

a) Very high cost. Annual lease cost is $3,000-$10,000 (depending upon whether obtained from a university or a private corporation) plus lease or purchase cost of terminal (another $5,000-$7,000). In addition, the connected nature of the system requires connection through the Bell Telephone System, with rapidly increasing costs.

b) The connectedness makes all users vulnerable when there is a computer malfunction. There also is a potential security problem, with clever students "poking around" in the system.

c) In the standard mode, with PLATO IV terminals, there is no hard copy available. This is available on the PLATO V terminal, but adds $1,000-$2,000 to the terminal cost.

d) By its nature, PLATO has no color capability.

e) Cannot be used in a full-class mode; i.e., the teacher and his/her class cannot simultaneously observe what is happening on the screen without the addition of expensive PLATO terminals. This mode is useful pedagogically and helps to reduce the per-pupil cost of operating the system.

f) Students cannot be taught the conventional programming languages (FORTRAN, BASIC, etc.), although they can program in TUTOR. There is a limited capability to program in conventional language, but this is discouraged because these languages are imbedded in TUTOR and operate very inefficiently.

g) The terminals are heavy and bulky and hence discourage faculty and students from bringing them home overnight or over the weekend.

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* Some educators consider portability to be desirable, while some do not. If school security is a problem, then portability may be undesirable.

IV. TERAK

A. System Overview

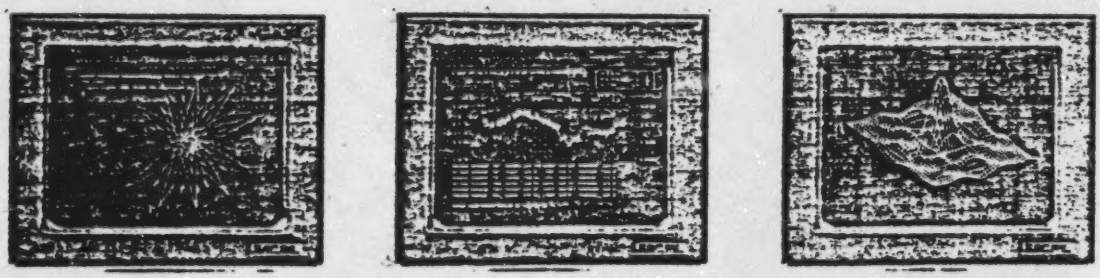
TERAK is a stand-alone microcomputer system manufactured by the TERAK Corporation of Scottsdale, Arizona. It has been available since the fall of 1977 at the cost of $5,500 to members of Educom. The system is pictured in Fig. IV.1.

TERAK is built around the Digital Equipment Corporation (DEC) LSI-11 single-board computer. It is a 16-bit machine with 28K words of memory. The system includes a 12-inch, black-and-white monitor with a composite video signal available to permit connection of additional video monitors for group display; a 71-key, full-size keyboard, with a number pad; and an 8-inch floppy disc drive with 262K bytes of storage space per disc. Up to three additional disc drives may be connected to the system.

TERAK provides the user with three languages: APL, BASIC, and FORTRAN. In addition, there is a powerful version of PASCAL available from Dr. Kenneth Bolls of the University of California at San Diego which has powerful graphic commands embedded in it.

The terminal has a screen resolution of 320-dots wide x 240 dots high (i.e., 76,800 dots) and displays text in 24 eighty-character lines. Graphic displays and text may be intermixed. The user may define special characters as any combination of dots within an 8-dot x 10-dot character space. Special sets of characters are available for APL and for several foreign languages. The quality of the graphics obtainable with TERAK is shown in the sample outputs of Fig. IV.2.

Fig. IV.1. The major components of TERAK.



Actual photos of the graphics/text combinations attainable with the 8510/a

Fig. IV.2. Samples of graphics obtainable with TERAK.

The $5,500 purchase price mentioned above does not include any system software. The RT-11 software may be purchased for an additional $850. For an additional fee of $200 per year, the user may purchase PASCAL with periodic updates.

Because TERAK only has been available for a few months and because relatively few have been sold, there is little courseware available at the time of this writing.

B. The Strengths and Weaknesses of TERAK

In this Section, we shall attempt to summarize the strengths and weaknesses of TERAK from the viewpoint of the educator.

1. Strengths of TERAK

a) High-quality graphics (76,800 point resolution) with 24 eighty-character lines.

b) Stand-alone system. There are no communications costs and no problems with system security.

c) System supports powerful programming languages.

d) Large disc storage capacity.

e) Contains interface for hard-copy terminal.

f) Permits file operations.

g) Full-size keyboard with number pad.

h) Lots of software available from DEC and from PDP-11 user community.

i) Composite video signal available to connect additional video monitors to permit group viewing of terminal screen.

2. Weaknesses of TERAK

a) System costs $5,500 plus about $1,000 for software.

b) The system design is very powerful and very flexible, but is very complex in its operation. It is difficult for the neophyte to operate.

c) There is little courseware available.

d) There is no authoring language, although Dr. Larry Wittie of the State University of New York at Buffalo is developing one.

e) The system is not connected; hence there is no inter-person communication.

f) The system is relatively bulky and is difficult to transport.

g) The system consists of three separate parts which require cables to interconnect them. This is undesirable in an educational setting, because of the possibility of misplacing or damaging cables.

h) There is no base of experience in educational settings.

i) There is no color capability.

j) There is no structure in the system for gathering student performance data.

V. COMPUCOLOR II

A. System Overview

Compucolor II is a stand-alone computer system announced in the spring of 1978 by Compucolor Corporation of Norcross, Georgia. Although this is a new computer, it is closely related to the Intecolor 8051, a computer available for about two years from Intelligent Systems Corporation, the parent company of Compucolor. The system is shown in Fig. V.1.

The display on the Compucolor screen (on a 13-inch high-resolution monitor) has a resolution of 128 dots wide x 128 dots high (or 16,384 dots), each one of which can be displayed in any one of eight colors. Either 16 or 32 lines of 64 characters may be displayed intermixed with graphics. The programmer may generate images using dot, vector, bar graph, or character plotting modes (the characters may be chosen from a set of 128 characters). Selective erase is relatively easy.

The purchaser may choose from among three standard-size keyboards with numbers of keys ranging from 77 keys to 117. On the latter, there are a number pad, single key-stroke keys for color section, two key-stroke keys for commands in BASIC (e.g., PRINT, SAVE, POKE) plus a variety of other special-purpose keys.

A mini-floppy disc drive with 51.2K byte capacity is built into the monitor cabinet as are all the other electronic components except the keyboard, which connects to the computer by cable.

The computer uses an 8080 microprocessor with 16K bytes of read-only memory (containing BASIC, a file control system, and terminal control software), and between 8K and 36K of read/write memory for user work space. An additional 12K bytes of read-only memory may be added.

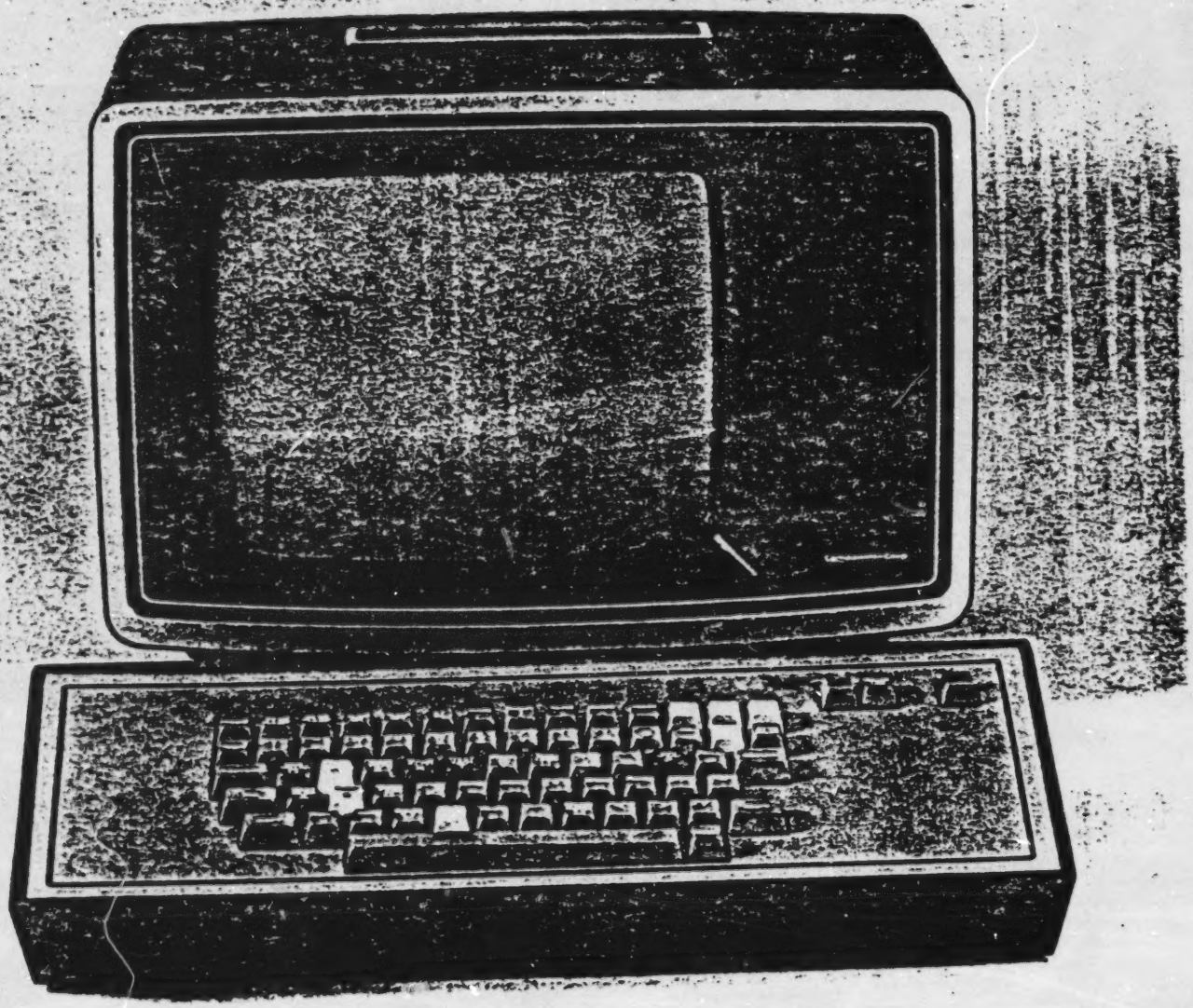


Fig. V.1. The Compucolor II system.

The Compucolor BASIC is very powerful, including all the usual commands and functions plus string functions, graphics commands, file commands, and the ability to enter and execute machine language programs from a BASIC program.

The model system most likely to be of interest to the educator includes 8K of read/write memory and the graphics package and costs $1,495 with discounts available for quantity purchases.

B. The Strengths and Weaknesses of Compucolor II

1. Strengths of Compucolor II

a) Good graphics capability, but requires care in programming.

b) Eight-color displays possible with foreground and background colors separately programmable.

c) Very good file-handling capability.

d) Relatively low purchase cost.

e) Disc for program storage permits fast program loading (about 3 seconds).

f) Full-size keyboard. Special keys available.

g) Stand-alone system so there are no communication costs or security problems.

h) System has a standard input-output port (RS232 and current loop) to permit connection of teletypewriters and other printing terminals.

i) Powerful BASIC interpreter.

j) Some key words are available with only two key strokes.

k) Good potential system reliability because entire computer is on a single board.

l) Good machine language interface to BASIC.

2. Weaknesses of Compucolor II

a) Because the computer only was announced in April, 1978, there is no base of experience available.

b) Because the computer is new, there is almost no courseware available.

c) The display system uses a high-resolution cathode-ray tube which requires a 30-MHz bandwidth (much higher than the 3-5 MHz used in conventional monitors); hence, it isn't possible to connect multiple monitors for classroom viewing. There is a version of the computer available with a 25-inch monitor for classroom use for $3,495. (In this author's experience, it is difficult for more than 15 people to read text simultaneously on a monitor of this size.)

d) There is no authoring language available, and none planned.

e) There is no structure built into the system for gathering student performance data.

f) The system includes no on-screen editor. This means that once a line is entered into the computer (by typing it in and hitting Return), it may only be modified by re-typing it.

g) Because the system is stand-alone, inter-person communication isn't possible.

VI. PET

A. System Overview

The PET 2001 computer system was announced in April, 1977, by Commodore Business Machines, Inc. It was the first complete computer system to be offered for under $1,000. The PET consists of a single-board computer (which uses the 6502 microprocessor), a keyboard, a 9-inch black-and-white monitor, and an audio-cassette recorder for mass storage. The price of this system is $795 for a system with 8K bytes of read/write memory for user work space.

PET has a powerful BASIC and operating system in 14K bytes of read/write memory. The operating system causes BASIC to be executed directly in ROM, so that all of the read/write memory is available to the user.

The cathode-ray tube screen displays 25 lines of 40 characters. The character set consists of 128 characters, each of which may be displayed direct (white on black) or reverse (black on white). Half of these characters are the conventional alphanumeric symbols, punctuation, and mathematical symbols; the other half are special graphic symbols (e.g., spade, heart, club, diamond, line segments of various thicknesses, box corners--both square and rounded, and line intersections). The keyboard displaying the symbols is shown in Fig. VI.1. Each symbol occupies one character space: up to one thousand may be placed on the screen at any one time. The symbols are designed in such a way that they may be grouped together in various ways to create interesting graphic images. Some examples are shown in Figs. VI.1-VI.4.

The PET keyboard has some very nice features and one quite bad one. The keyboard includes a numeric pad and a set of cursor and screen-control keys. In addition, all of the punctuation and mathematical symbols are in

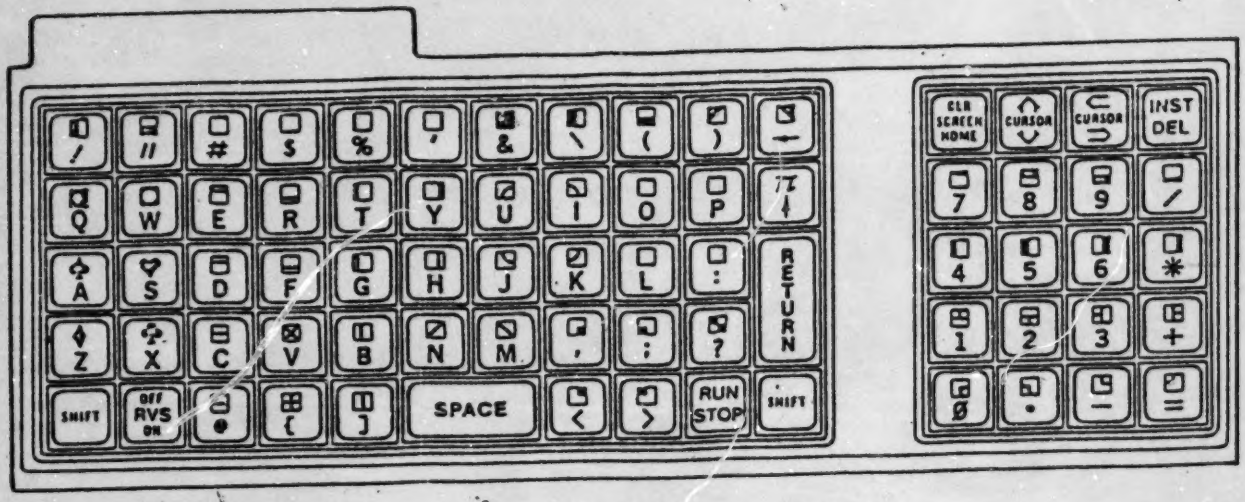


Fig. VI.1. The PET keyboard.

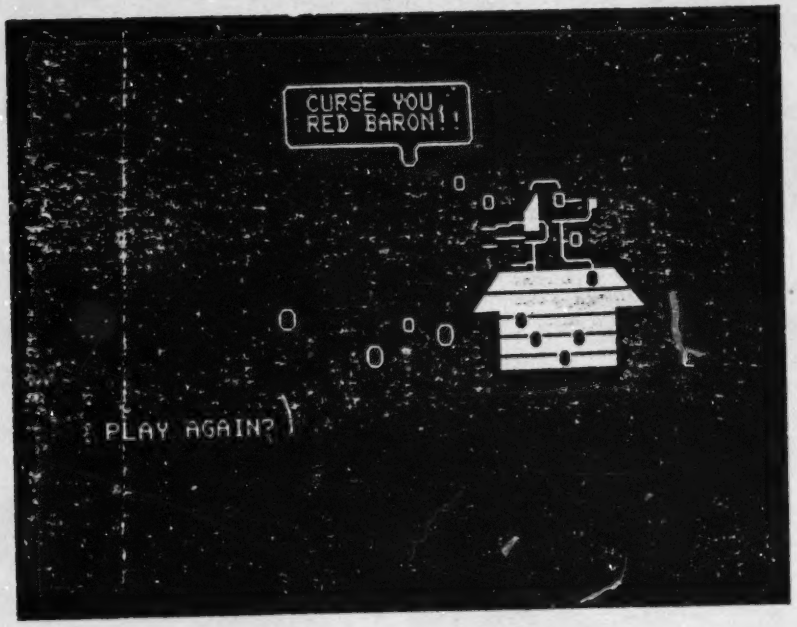


Fig. VI.2. Snoopy flying his Sopwith Camel.

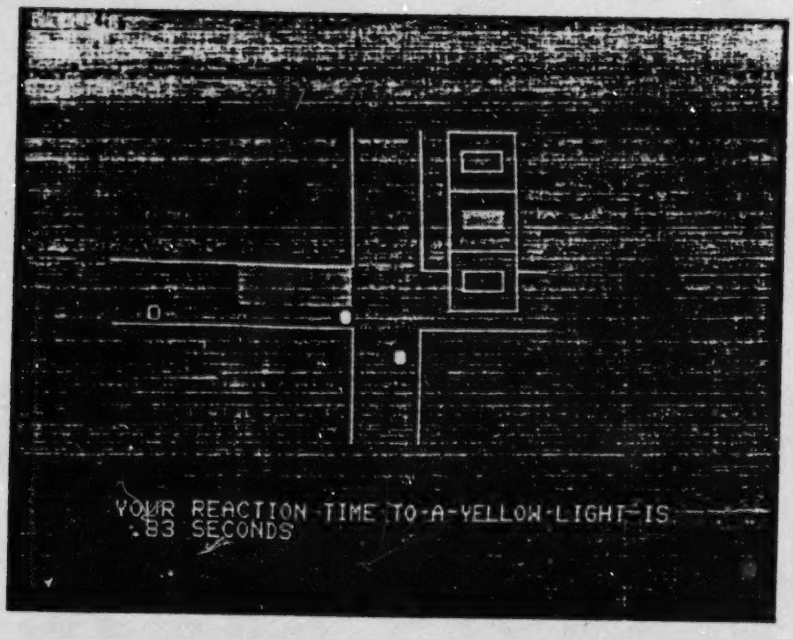


Fig. VI.3a. Traffic light and intersection with successful stop.

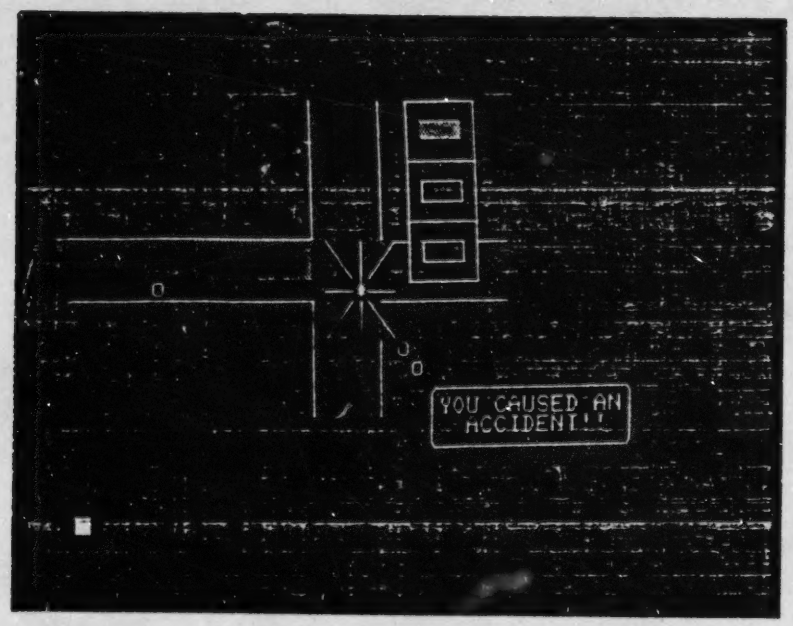


Fig. VI.3b. Same intersection with unsuccessful crossing.

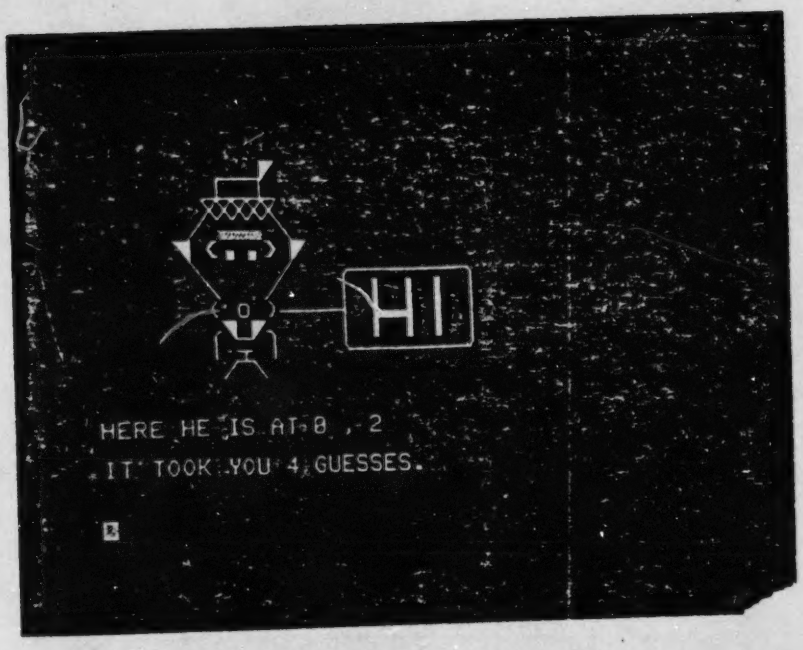


Fig. VI.4. The Hurkle comes out of hiding.

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the unshifted key position. This means that almost all typing may be done without using the shift key. The cursor commands permit powerful on-screen editing of programs. Characters may be changed, inserted, or deleted in any line which appears on the screen even after Carriage Return is struck. These cursor commands may be imbedded in a program which permits excellent print control, including production of simple animations.

The one weak point of the PET keyboard (and it is a major one) is its size. It's key-to-key spacing is only two thirds that of a conventional keyboard, which makes touch typing very difficult.

PET BASIC has file handling capability of limited capacity.

Although the PET does not provide a composite video signal to drive additional monitors, a simple modification designed by one of this author's colleagues (Marc Hertzberg), which may be installed easily and cheaply by an electronic technician, permits such connections to be made. There also is a commercial composite video adapter available for $19.95.

B. The Strengths and Weaknesses of the PET

1. Strengths of the PET

a) Low system cost

b) Reasonably good graphics

c) Powerful BASIC interpreter

d) Moderate-level file-handling capability

e) Powerful on-screen editing

f) Ports for connecting to external devices (e.g., IEEE 488, 8-bit parallel, and port for second cassette recorder).

g) All components in one case. This means that it is easy to move around. Unit may be taken home by faculty or students.

h) It has relatively easy access to machine-language programming through BASIC; however, the 6502 machine language is difficult to use.

i) There is a fair amount of courseware available. Ten thousand units have been sold, mostly to educators who are developing courseware. Since January 1, 1978, at least a dozen courseware distribution companies have been formed.

j) There is a base of experience (although limited) with classroom use.

k) Stand-alone system without communication cost. Not subject to security problems.

l) Good potential reliability because entire computer is on a single board.

m) System is compact and, hence, portable; although it weighs 44 pounds.

n) Keyboard layout very user oriented.

o) With simple modification, system can drive multiple monitors for classroom viewing.

p) Dot-matrix printer available which prints graphics characters. Uses cheap paper and prints at 120 characters per second. Cost is $595.

q) Floppy disc with capacity of 350K bytes to be available in fall 1978 for $1,000.

2. Weaknesses of the PET

a) Forty-character line makes plotting graphs more difficult than a wider line.

b) Key-to-key spacing is too small for touch typing.

c) Memory expansion requires addition of external box.

d) There is no color

e) Audio cassette program storage is cheap, but is relatively slow. The average program takes one minute to load, if it is the first program on the cassette.

f) Because system is stand-alone, inter-person communication cannot occur.

g) There is no built-in structure for gathering student performance records.

VII. SUMMARY COMPARISON AMONG COMPUTERS

In the preceding sections, we have looked at the properties of each of the four computers which we are studying. We have, so far, avoided comparisons among them. In this section, our specific purpose is to compare them. It is, perhaps, appropriate at this point to restate the purpose of this comparison: guidance for educators who are faced with the difficulty of deciding which computer to choose from among all of those available. This decision must be made in such a way that the needs of the user community (students and teachers) are satisfied within the budgetary and other constraints of the school system.

During the background development effort for this summary comparison, two alternative approaches to comparing the four computer systems were considered. One of these approaches focussed on the extent to which each of the subject computer systems is able to implement each of several applications of computers in education. This approach proved to be extremely difficult to develop for reasons which will be detailed below.

One general aspect of the difficulty relates to the relative ages of the systems considered. The PLATO system has existed in one form or another for almost two decades, while the PET has been available for only one year, TERAK for eight months, and Compucolor II is so new that no units have been delivered at the date of this writing. This means that there is a vast amount of experience with developing educational applications on PLATO, some experience* on the PET, limited experience on TERAK, and essentially none on

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* This author's group at Stony Brook has nine months of experience programming the PET, with the first six devoted primarily to learning how to use the new and unique features of the machine (graphics, screen editting, GET Command, etc.). This learning period has involved also trading experiences with other PET groups such as Bob Albrecht's at Dymax, Karl Zinn's at the University of Michigan, and Arthur Leuhrmann's at Lawrence Hall of Science. The point here is that one doesn't learn how to use machines such as we are considering without many months of intensive effort.

Compucolor II. There appears to be no person or no group in this country with significant levels of experience developing materials for more than one of our systems. This means that any comparison of these computers with respect to curricular applications would be very speculative (except for PLATO and perhaps for the PET--to a limited degree), foolhardy, and potentially unfair to some or all of the computers.

There is another element of difficulty in an applications-focussed comparison which is related to the characteristics of the machines considered. This author had planned to compare these computers in three of the major application areas appropriate to education: computer-assisted instruction (CAI), programming, and simulation. In each of these areas, there is one system which is dramatically better than, or inferior to, the rest.

In CAI, all four computers can be programmed to provide computer-assisted instruction; however, PLATO is the only one which is capable of complex, multiply-branched CAI, with detailed records being kept of student performance. All of the others are able to provide only elementary forms of CAI and cannot collect student data. The designers of PLATO specifically included implementation of CAI in the system design specifications, whereas the designers of the other systems did not.

Comparison on the basis of application of the computer to teach programming and problem solving reveals exactly the opposite circumstance. Compucolor II, PET, and TERAK all would be considered by most educators to be useful in this educational application because they have available programming languages which are relatively universal, whereas PLATO essentially offers only TUTOR which was designed for other purposes.

In the third area, simulation, the GENE I simulation from the Huntington Computer Project was chosen for consideration because it is relatively widely

known and because a similar simulation has been done on PLATO and also is widely known. GENE I is a simulation of the transfer of non-sex-linked genetic characteristics from parent to offspring. It was written originally for teletypewriter output and, so, included no graphics. The PLATO version, on the other hand, was designed, in part, to demonstrate the graphic capability of the PLATO terminal. It focussed on genetic transfer in drosophila and displayed the parents and offspring as seen in Fig. III.1. With PLATO it was possible to display normal and vestigial wings, abdominal banding, and the major external sexual difference between males and females (rounded versus pointed tail). Again, comparison can be made only with great difficulty. PET and Compucolor II have graphic capability which is totally inadequate to challenge PLATO in this task, and TERAK with one-third the resolution of PLATO probably isn't adequate either--although without experience programming TERAK, it isn't possible to state this with certainty.

Our experience with microcomputers is so limited that this approach to comparing machines seems unlikely to be fruitful. This is especially unfortunate because such comparisons are precisely the kind which are most appropriate to help educators to make decisions in this area.

The other approach to comparisons among the four computers involves the identification of a set of parameters in terms of which comparisons may be made. The educator's decision making would be simplified greatly if the set of parameters could be reduced to a single number specifying a performance measure. This is impossible for at least two reasons: 1) at least some of the parameters are qualitative and cannot easily be assigned a numerical value; and 2) each decision maker would weigh the importance of each parameter in a unique way (probably subjectively) so that any single performance measure determined by this author would not be useful.

The basis of our comparison is the vector of 25 parameters in Table VII.1. These parameters have been chosen will full knowledge that parameters which are important to some people may have been omitted and others which are unimportant to some people have been included.

Each person studying Table VII.1 and Sections II-VI will come to a personal ordering of the four computers in our study (and the classes which they represent). There is an obvious quagmire here to entrap anyone foolhardy enough to attempt to state his views in writing. It is, of course, impossible to avoid upsetting system developers and manufacturers--nonetheless, this author shall express his views as generated from this study.

If it were not for system cost, the clear choice is PLATO. Unfortunately, educators cannot ignore cost--in fact, it is a primary consideration in almost all educational institutions. For this reason, it appears that the probability that PLATO terminals will become widely available is very small. PLATO, because of its power and flexibility, undoubtedly will continue to be very useful in educational research and will continue to demonstrate what the possibilities are, but it is unlikely to appear in the mass of educational settings.

TERAK also is a fine computer with considerable potential to impact education; however, its price also is substantially over the cost thresholds in most academic settings. In addition, the TERAK system was designed for maximum flexibility. This flexibility makes TERAK very attractive to computer scientists but makes system operation sufficiently difficult for the non-computer scientist that most will reject it.

Neither PLATO nor TERAK is likely to penetrate deeply into the educational scene because of its high cost. This is distressing because of their fine qualities, but in the real world, school budgets have been tight for several years, even without inclusion of the impact of Proposition 13. On the basis of this

Table VII.1 Comparison Among Computers

Parameter	PLATO	TERAK	Compucolor II	PET
1. Cost	$3,000 - 10,000 annual lease	6.500	$1,395 (8k user memory)	$795 (8k user memory)
2. Courseware available	large amount	small amount	almost none	moderate amount
3. Student performance data available	yes	no	no	no
4. Graphics resolution	262k dots	76.8k dots	16.4k dots	16k dots(1)
5. Graphics flexibility	very flexible	very flexible	moderately flexible	least flexible
6. Ease of programming graphics	very easy	very easy	moderately difficult	moderately easy
7. Screen size (characters)	2048 (32 x 64)	1,920 (24 x 80)	2,048 (32 x 64)	1,000 (25 x 40)
8. Color	no	no	yes	no
9. Connected system	yes	no	no	no
10. Authoring language	yes	under development	no	no
11. Keyboard layout	good	good	moderately good	excellent
12. Keyboard size	full size	full size	full size	small
13. Keyboard quality	professional	professional	professional	calculator
14. Hard copy output	no(2)	interface provided	interface provided	printer available
15. Mass storage types	disc	floppy disc	floppy disc	audio cassette recorder(3)
16. Mass storage speed	1 - 3 sec.	1 - 3 sec	1 - 3 sec	1 min.(4)
17. Mass storage capacity	megabytes	262k bytes	75k bytes	125k bytes(5)
18. Programming languages available	TUTOR(6)	PASCAL, APL, BASIC, FORTRAN	BASIC	BASIC
19. Machine language programming	no	yes	yes	yes
20. Composite video signal	no	yes	no	yes(7)
21. User memory space	virtually unlimited	28k bytes	8k bytes	8k bytes
22. Portability	not portable	not easily portable	moderately portable	portable
23. Ease of program editing	easy	easy	moderately difficult	very easy
24. Output ports	none(8)	RS232	RS232	IEE488, parallel port
25. User defined graphic characters	yes	yes	yes	no

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Notes for Table VII.1

1. The resolution of the PET is difficult to specify. The screen has 1,000 screen positions (40 chracters per line x 25 lines). Each character is defined by an 8 x 8 dot matrix, so that the potential resolution is 64,000 dots. Clearly, because only 128 characters have been defined, the resolution is considerably less than 64,000. The 16,000 dot resolution in the table was chosen as a compromise between 64,000 and 1,000, on the basis that the average character uses 16 dots.
2. There is no hard copy on the PLATO IV terminal, but users can transfer data to a hard-copy terminal.
3. Floppy disc to be available, Fall, 1978.
4. One minute is the average loading time for a program from beginning to end, assuming no searching. The fifth program on a cassette takes four minutes to search and one minute to load.
5. This is the storage capacity of a 30-minute cassette.
6. BASIC and FORTRAN are available, but they are inefficient.
7. With commercially available $20 adapter.
8. None on PLATO IV, but available on new PLATO V terminal.

author's experience, there is little likelihood that computer systems so far above educational cost thresholds will find their way into the classroom, no matter how impressive the other 24 parameters may be.

Choosing between Compucolor II and PET is considerably more difficult. Both machines are below the cost threshold mentioned earlier. Compucolor II has high-quality color, a floppy disc, and twice the number of screen characters as PET, as well as a better keyboard and better file handling capability; however, it costs almost twice as much as a PET. This raises an interesting but troubling question: Is a school (choosing between Compucolor II and PET) better off buying one Compucolor II because--in several ways--it is better than PET, or is it better off buying two PETs and sacrificing some quality for quantity? Stated another way: Will twice as many students achieve any given level of learning using Compucolor II than they do with the PET?

This question has troubled this author for some time and has caused him to "invent" a unit for comparisons among machines. That unit is the PET. The cost of any computer may be measured in terms of PET equivalents. In cost, Compucolor II equals two PETs; TERAK equals eight PETs, etc. Now one may ask, "Will the computer system which I am considering impact P times as many students as the PET?" Unless it does, in some cloudy sense, the cost/benefit ratio is tipped in favor of the PET (or one of the other machines in its class).

The questions raised in this report have been answered inadequately, primarily because the new personal computers have been available for too short a time to permit crisper answers. It is clear that time and energy must be expended in an effort to develop the information base educators need to guide them in decision making.

VIII. ACKNOWLEDGEMENTS

The gathering of information and development of perceptions for such a study as this one are much more than a one-person job. The character and accuracy of statements contained in this report are the responsibility of this author; however, many people have helped with the evolution of this report. Among them are:

Mr. Arthur Melmed, National Institute of Education

Dr. John May, National Institute of Education

Dr. Robert Davis, University of Illinois, Urbana

Dr. Bruce Sherwood, University of Illinois, Urbana

Dr. Martin Seigal, University of Illinois, Urbana

Dr. Stanley Smith, University of Illinois, Urbana

Dr. Larry Wittie, State University of New York, Buffalo

Mr. Charles Meunch, Compucolor Corporation

Mr. Charles Peddle, Commodore Business Machines

Mr. Philip Reese, State University of New York, Stony Brook

Ms. JoAnn Comito, State University of New York, Stony Brook

Mr. Robert Wlezien, State University of New York, Stony Brook

A special acknowledgement must be made of the major contribution made by Mr. Marc Hertzberg of the State University of New York at Stony Brook. He spent many hours travelling to gather information and discussing the ideas with this author, as well as making certain that the author's comments were reasonably accurate.

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APPENDIX A

A GLOSSARY OF TECHNICAL TERMS

APL, an acronym for A Programming Language, is a high-level programming language developed over a decade ago by Kenneth Iverson at IBM. It is a very powerful and very compact language but is not available on many computers at the present time.

BASIC is a high-level programming language developed over a decade ago by John Kemeny and Thomas Kurtz at Dartmouth. It is the most widely used language in educational applications, and it is available on most microcomputers.

Bit is a contraction of "binary digit," the basic element of the binary number system. Binary numbers are used to express data and instructions in most computers. A bit also is the elemental component of computer memory. Each binary digit is stored in a single memory cell.

Byte is a term used to describe an eight-bit number. Memory size in a computer frequently is defined in terms of bytes, partly because alphabetic and numerical characters are encoded as single bytes.

Compiler. A compiler is a large-scale computer program which translates computer languages like APL, BASIC, and FORTRAN into a language (called machine language) which the computer can understand. It also checks the user's programs to ensure that there are no syntactical errors, assigns parts of memory for storage of variables, and performs a number of other "housekeeping" chores.

Courseware refers to computer software which is related to curriculum in educational settings.

File operations are operations (e.g., averaged, sorting, etc.) performed by the computer on sets of data called files. A file is a specific set of data (e.g., the grades obtained by an individual student on all exams in a course, or the final grades of all students in a course) stored in the memory of a computer.

Floppy disc. A floppy disc is a relatively low-cost mass memory device used to store data or programs until they are needed by the computer. The disc is made of thin flexible plastic (hence the term "floppy") coated with a magnetic film on which information is stored as magnetic "spots." The disc is placed in a disc drive which spins it, much like a phonograph record, and reads off the magnetically encoded information, converting it into an electrical form which the computer can use.

FORTRAN is the most widely used scientific programming language. It was developed twenty years ago and has been improved upon in many ways by more modern languages, but it still is important because of the billions of dollars of software which has been written in FORTRAN and which still is in use.

Hardware is a general term used to refer to the physical part of a computer--the electronic systems and components as well as the mechanical ones. It is complementary to the computer software (c.f., below).

High-level language. People communicate information (data and instructions) to computers in a form which is encoded according to a precise set of rules. This set of rules is called a language by analogy with natural (i.e., people) language. The term higher-level refers to languages which are easy for people to understand, but difficult for machines to understand. (See definition of machine language below.)

Machine language. Computers recognize instructions and data only when expressed in terms of binary numbers. Each of the operations which is permissible on a specific computer is expressed as a binary number. Most people have great difficulty memorizing the strings of binary digits corresponding to the instructions for their computer (these strings are as long as 60 bits), especially when writing complex programs using hundreds or even thousands of individual instructions. (See definition of higher-level language above.)

Memory. The electronic circuits in which the computer program and data are stored is called memory by analogy with human memory. Memory size usually is expressed in terms of the number of bytes (i.e., 8-bit cells) contained in it. Because useful amounts of memory number in the thousands, the usual unit of measure is the kilobyte. Actually, a kilobyte is not 1,000 bytes as one might expect, but is 1,024 bytes. There is no good reason for this except that 1,024 is two raised to the tenth power. To extrapolate, 1K byte = 1,024 bytes; 2K bytes = 2,048 bytes; 4K bytes = 4,096 bytes, etc.

Microcomputer. A microcomputer is a computer built from small microcircuits (circuits on a one-square-centimeter chip of silicon and contains tens of thousands of transistors). Such computers characteristically cost in the range of $1,000 - $3,000 and are about the size of an electric typewriter. Usually microcomputers used in educational environments have memory sizes in the range of 4K-16K bytes; however, microcomputers with memories of as large as one million bytes are available.

Minicomputer. A minicomputer usually is one with a cost in the range of $5,000 - $100,000 and is about the size of a filing cabinet. Recently the distinction between minicomputers and microcomputers has begun to blur as manufacturers have begun using microcircuits in the design of minicomputers.

PASCAL is a relatively new computer language. It has become popular among computer scientists, partly at least because it compels the user to construct programs in a very orderly easy-to-read manner. (Computer scientists talk about structured programming.)

Program. A program is a set of instructions to a computer to carry out the solution of a specific problem. The program as communicated to the computer is expressed in terms of a computer language (c.f., definitions of higher-level and machine language above).

Random access memory (RAM). Originally the term random-access memory meant any memory in which any randomly selected location in the memory could be accessed as rapidly as any other location. Since the advent of microcomputers and their semiconductor memories, this term has been reserved for read/write memory (c.f., definition below).

Read-only memory. Read-only memory is memory which may be read by the computer but which cannot be modified. It is random-access memory according to the definition above but is referred to as read-only memory, or ROM, an acronym.

Read/write memory is a form of semiconductor memory which may be read by the computer and which may be modified (i.e., written into) by the computer. Because such memory may be modified when the electrical power is removed, whatever was in the memory disappears. Such memory is said to be volatile because its contents "evaporate" on removal of power. This kind of memory is random-access memory according to the definition above. The term random-access memory or RAM is reserved for this kind of memory.

Software is a general term used to refer to all of the programs required to get the computer hardware to operate. It includes compilers, courseware, and operating systems (large programs which play the same role in a computer as the conductor plays in a symphony orchestra). Software essentially is the information which is stored in the computer's memory and is somewhat more nebulous than the hardware which is physical and can be touched and weighed. It is, nonetheless, very real.

Time sharing is a special way to use computers which was developed about 1965 by Corbato at MIT and Kemeny and Kurtz at Dartmouth. It refers to the sharing of the resources of the computer among a group of users where the users are executing their programs essentially simultaneously. It represented a major breakthrough in computer use, permitting large numbers of educators to obtain computer support at substantially reduced prices.